TECHNICAL REPORT
NATICK/TR-83/020

AD-A143 314

FUNGAL SUSCEPTIBILITY OF MILITARY PAINT FORMULATIONS - PHASE ONE

BY
D. L. KAPLAN
M. GREENBERGER
B. J. WILEY
AND
A. M. KAPLAN

NOVEMBER 1982

UNITED STATES ARMY NATICK
RESEARCH & DEVELOPMENT LABORATORIES
NATICK, MASSACHUSETTS 01760

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

SCIENCE & ADVANCED TECHNOLOGY LABORATORY

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NATICK/TR-83/020	2. GOVT ACCESSION NO. A143314	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) FUNGAL SUSCEPTIBILITY OF MILITARY PAINT FORMULATIONS - PHASE ONE		5. TYPE OF REPORT & PERIOD COVERED Interim Report March 82 - November 82
		6. PERFORMING ORG. REPORT NUMBER NATICK/TR-83/020
7. AUTHOR(s) David L. Kaplan, Marvin Greenberger, Bonnie J. Wiley and Arthur M. Kaplan		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Natick Research & Development Laboratories, Science & Advanced Technology Laboratory, DRDNA-YEP, Natick, MA 01760		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Program Element 6.2 Project 1L162723AH98 Work Unit CH001
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Natick Research & Development Laboratories, Science & Advanced Technology Laboratory, DRDNA-YEP, Natick, MA 01760		12. REPORT DATE November 1982
		13. NUMBER OF PAGES 46
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

FUNGAL SUSCEPTIBILITY, COATINGS, CHEMICAL AGENT RESISTANCE, WEATHERING, FUNGAL DETERIORATION, LEACHING, FUNGAL GROWTH, PAINTS, CAMOUFLAGE

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Eleven Military paint formulations on metal panels were evaluated for fungal susceptibility before and after weathering and leaching. TT-E-527 and TT-E-529 (olive drab) and MIL-E-52798A (forest green camouflage) formulations supported moderate fungal growth after six weeks in plate tests or 13 weeks in tropical chamber tests. MIL-C-46168A (chemical agent resistant) formulation supported slight growth during this period. Overgrinding or the inclusion of fine beads to improve paint smoothness did not improve fungal resistance of either the

DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

PREFACE

As a result of discussions held during the 30th Conference on the Prevention of Microbiological Deterioration of Military Materiel and Systems, Natick, MA, November 1981, NATICK/TR-82/027, the field and specification problems with Military paint formulations were brought to light. Subsequently, US Army Natick Research & Development Laboratories (NLABS), in cooperation with Mobility Equipment Research & Development Command (MERADCOM), undertook this study to provide a scientific basis for the evaluation of Military paint coatings. In the interim, requests have been received from USA Material Development & Readiness Command (DARCOM), Communications Electronic Command (CECOM), Test and Evaluation Command (TECOM) and the Air Force for this information.

This study was funded under the Natick 6.2 program on the prevention of microbiological deterioration of military materiel, 23223415001. We thank Jon Polishook, Richard Roat and Eileen Bullard for their technical assistance.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF APPENDICES

LIST OF APPENDICES (CONT'D)

FUNGAL SUSCEPTIBILITY OF MILITARY PAINT FORMULATIONS - PHASE ONE

INTRODUCTION

Fungal deterioration of paint coatings potentially can lead to a number of problems including the loss of functionality of equipment, accelerated corrosion of metals, acceleration of the chemical deterioration of materials due to fungal metabolites, loss of chemical agent resistant characteristics, and a compromise of camouflage characteristics.

Recently, field contamination problems due to fungal growth on a high percentage of Lance M251 warheads and their containers have been documented. Interim cleaning and/or repainting procedures have been issued and chemical agent resistant coatings (MIL-C-46168A)[1] are being substituted for the previously used enamel alkyd camouflage forest-green formulations (MIL-E-52798A).[2] However, limited information is available on whether the chemical agent resistant formulation provides improved protection from fungal contamination, or if a biocide or change in paint texture will improve the fungal resistant characteristics of either paint formulation. Results of this study are needed in order to advise field personnel of the best Military paint formulation to use to achieve the desired field performance.

[1]United States Department of the Army. 1978. Military Specification. Coating, Aliphatic Polyurethane, Chemical Agent Resistant. MIL-C-46168A (MR). US Army Materials and Mechanics Research Center, Watertown, Massachusetts.

[2]United States Department of the Army. 1976. Military Specification. Enamel, Alkyd, Camouflage. MIL-E-52798A (ME). US Army Mobility Equipment Research and Development Command, Fort Belvoir, Virginia.

Eleven paint formulations, including four chemical agent resistant paints, on metal panels, were furnished by MERADCOM. Formulation variables included polymer base, grind, beads, and fungicide. The panels underwent extensive evaluation for fungal susceptibility in plate and tropical chamber tests before and after weathering and leaching. Accelerated weathering tests were run under xenon, fluorescent and carbon arc exposures.

This interim report will provide a basis on which to make rational decisions on the best formulations available for fungal resistance. Once final evaluations are completed and results are obtained on chemical agent resistance and camouflage characteristics before and after weathering and exposure to fungal growth, scanning electron microscopy, and evaluation of paints on a wooden matrix, then a final report will be issued.

MATERIALS AND METHODS

Weathering Studies: Eleven types of painted panels (Table 1), 4" x 12" (10.2 cm x 30.5 cm), were received in March 1982 from MERADCOM for microbial evaluation before and after leaching and weathering. Weathering exposures included both accelerated weathering (carbon arc, fluorescent, and xenon arc) and outdoor exposure at NLABS Hudson, MA exposure racks.

Table 1. Paint Formulations

A. Olive Drab - enamel alkyd

1. TT-E-527, lustreless
2. TT-E-529, semigloss

B. Forest Green - enamel alkyd, camouflage

1. MIL-E-52798A, control
2. MIL-E-52798A, overground
3. MIL-E-52798A, 25 µm vesiculated polyester beads
4. MIL-E-52798A, 1% Vancide 89RE*
5. MIL-E-52798A, 2% Vancide 89RE

C. Chemical Agent Resistant - aliphatic polyurethane

1. MIL-C-46168A, control
2. MIL-C-46168A, 25 µm vesiculated polyester beads
3. MIL-C-46168A, 1% Vancide 89RE
4. MIL-C-46168A, 2% Vancide 89RE

*Purified, captan, N-trichloromethylthio-4-cyclohexane-1,2, dicarboximide (R. T. Vanderbilt Co., Norwalk, CN)

Fluorescent and xenon arc exposures, performed under contract with LeBlanc Research Corp., N. Kingston, RI, were forwarded 2 April 1982 and returned after exposure approximately 7 July 1982. Method 5804 of Federal Test Method Standard 191A was used for carbon arc exposure.[3] Black panel temperature was 68 $\pm$ 5^{o}C with cycles of 102 min light without spray followed by 18 min light with spray. Method 5830 of Federal Test Method Standard 191A for leaching was used with 24-hours exposure to a continuous flow of water at 27^{o}C to 29^{o}C. ASTM Method G53-77 for fluorescent exposure was used with cycles of 8 hours UV at 60^{o}C followed by 4 hours condensation at 40^{o}C.[4] ASTM Method G26-77 for xenon arc exposure was

[3]United States Government Printing Office. 1978. Federal Standards for Textile Test Methods. FED. TEST METHOD STD. No. 191A. Washington, DC.

[4]American Society for Testing and Materials. 1982. Annual Book of ASTM Standards. Part 41. General Test Methods, Nonmetal; Laboratory Apparatus; Statistical Methods; Space Simulation; Durability of Non-metallic Materials. Philadelphia, PA.

used with a black panel temperature of 63 $\pm$ 3°C and cycles of 102 min light without spray followed by 18 min light with spray.[5]

Fluorescent light exposure was conducted on a QUV accelerated weathering tester, Q-Panel Co., Cleveland, OH. Xenon arc exposures were run on an Atlas C:35 W Weather-Ometer, Chicago, IL. Carbon arc exposures were on a Sunshine Carbon Arc Model XW-W Atlas EIEC Device, Chicago, IL.

During May through June 1982, the panels were subdivided into approximately 2-inch squares (5 cm^2) for visible and infrared reflectance measurements, and approximately 0.5-inch squares (1.3 cm^2) for scanning electron microscopy studies. A total of 3,045 samples were evaluated during the course of this study.

<u>Plate Testing</u>: Environmental Test Methods, MIL-STD-810C, Method 508.2, was followed.[6] Mineral salts solution contained the following:

KH_2PO_4	0.7 g
K_2HPO_4	0.7 g
$MgSO_4 \cdot 7H_2O$	0.7 g
NH_4NO_3	1.0 g
NaCL	0.005 g
$FeSO_4 \cdot 7H_2O$	0.002 g
$ZnSO_4 \cdot 7H_2O$	0.002 g
$MnSO_4 \cdot H_2O$	0.001 g
Distilled H_2O	1000 mL

The pH of the salts was 6.0 to 6.5. Mineral salts agar was prepared by adding 15.0 g agar per liter of mineral salts solution.

[5] See reference 4, p. 7.

[6] United States Department of the Air Force. 1975. Military Standard. Environmental Test Methods. MIL-STD-810C. Wright-Patterson Air Force Base, Ohio.

The following fungi were used to prepare the mixed spore suspension:

QM 386	*Aspergillus niger*
QM 380	*Aspergillus flavus*
QM 432	*Aspergillus versicolor*
QM 471	*Penicillium funiculosum*
QM 459	*Chaetomium globosum*
QM 279c	*Aureobasidium pullulans*

The final spore suspension contained $1 \times 10^6 \pm 2 \times 10^5$ spores per mL in mineral salts solution.

Petri dishes containing mineral salts agar were prepared containing sterile 5.0-cm filter paper discs. The test and control specimens were inoculated with the mixed fungal spore suspensions by spraying the suspension onto the painted panels and control filter paper discs using a sterilized atomizer. The Petri dishes containing 2-inch square (5-cm^2) test specimens were incubated at 30°C.

<u>Chamber Studies</u>: Tropical chamber exposure for 13 weeks (91 days) was begun July 14 and 15, 1982, for xenon and fluorescent exposed specimens and July 27, 1982, for carbon arc exposed specimens. Tropical chamber exposure terminated October 6 and 7, 1982 for xenon and fluorescent exposed specimens and October 26, 1982 for carbon arc exposed specimens. Method 508.2 of MIL-STD-810C for tropical chamber exposure was followed, using the fungal spore suspension prepared for the plate testing. Temperature and humidity were cycled at 30°C $\pm$ 1°C and 95% RH for 20 hours, followed by 4 hours at 25°C $\pm$ 1°C and 100% RH.

<u>Light Photomicroscopy</u>: Light photomicrographs were taken using a Zeiss Stereomicroscope equipped with two low-voltage illuminators for reflected light, a phototube and Basic Body II, and a camera adapter for using Polaroid film holders and 4" x 5" (10.2 x 12.7 cm) Type 52 film. Selected specimens were from plate test samples.

Continuing Studies: Susceptibility of outdoor weathered samples will be determined after sufficient outdoor exposure time has elapsed. Scanning electron microscopy of selected specimens is being conducted on a CWIKSCAN/100 (Nanometrics, Sunnyvale, CA). Final visible and infrared reflectance measurements of samples exposed in chamber studies will be completed by MERADCOM.

Evaluation of the same paint formulations on wooden substrates will be initiated in FY83, as will the evaluation of chemical agent resistance of the weathered and chamber exposed painted metal paints.

RESULTS

The fungal susceptibility of weathered and unweathered painted panels in plate testing after six weeks is detailed in Appendix A, Tables 1-3. The tropical chamber exposure results are described in Appendix B, Tables 1-3 and photomicrographs of representative specimens are presented in Appendix C, Figures 1-16.

In Appendix A, Table 1 it is apparent that the two olive-drab formulations (TT-E-527, TT-E-529)[7,8] support moderate fungal growth, whether or not they undergo weathering. In Appendix A, Table 2 the enamel alkyd camouflage forest-green paints (MIL-E-52798A) support moderate growth dependent on treatment. The control panels (B-1) support moderate growth throughout, with the exception of the 700-hour carbon arc exposure. The overground (B-2) and the bead (B-3) formulations show similar patterns as the controls, including the increase in

[7] United States Department of the Army. 1969. Military Specification. Enamel, Alkyd, Lustreless. MIL-TT-E-527C. US Army Materials and Mechanics Research Center, Watertown, Massachusetts.

[8] United States Department of the Army. 1969. Military Specification. Enamel, Alkyd, Semi-gloss. MIL-TT-E-529C. US Army Materials and Mechanics Research Center, Watertown, Massachusetts.

susceptibility with carbon arc exposure time. With 1% (B-4) and 2% (B-5) Vancide there is a progressive decre.‿e in susceptibility both in weathered and unweathered samples. The only exception is the carbon arc exposure, where susceptibility increases with exposure time.

In Appendix A, Table 3 the chemical agent resistant paints (MIL-C-46168A) support sparse to no growth. The control (C-1) panels support sparse growth throughout, with and without weathering. Progressively less growth is evident with the bead (C-2), 1% Vancide (C-3), and 2% Vancide (C-4) formulations. The 2% Vancide level provided complete protection from fungal attack in plate tests even up to 700 hours weathering.

Tropical chamber data for enamel alkyd olive-drab formulations are presented in Appendix B, Table 1. In general, these formulations supported light, moderate or heavy growth before or after weathering. The TT-E-529 semigloss (A-2) was more susceptible than the TT-E-527 lustreless (A-1) formulation.

Appendix B, Table 2 presents tropical chamber results for the enamel alkyd camouflage forest-green formulations. These formulations were less susceptible than the semigloss and lustreless paints (olive drab), but still supported significant fungal growth depending on formulation. The control panels (B-1) supported light to heavy growth and this susceptibility was not reduced by overgrinding (B-2) to create a smooth finish. The addition of vesiculated beads (B-3) appeared to slightly delay the onset of growth, but no overall difference in susceptibility was evident by the end of the exposure period. The addition of 1% Vancide (B-4) and 2% Vancide (B-5) delayed the onset of growth up to six weeks and provided significant improvement in prevention of fungal

contamination, even after 700-hours weathering in xenon and fluorescent systems. The protection from fungal growth deteriorated in carbon arc exposure.

The tropical chamber results with chemical agent resistant formulations are presented in Appendix B, Table 3. These formulations provided improved resistance to fungal contamination, with delayed initiation of growth from 4 to 8 weeks and trace to light growth levels after 13 weeks. The incorporation of vesiculated beads (C-2) provided no improvement over the control (C-1) formulation. The addition of 1% Vancide (C-3) or 2% Vancide (C-4) provided minimal improvement in fungal susceptibility in fluorescent, carbon arc or xenon exposures and no delay in onset of growth.

Results from leaching of panels (see Appendix B, Table 3 carbon arc time zero ratings) indicated an enhancement of susceptibility of the enamel alkyd camouflage forest-green formulations while in general, no change in susceptibility was seen with the enamel alkyd olive drab or chemical agent resistant formulations.

DISCUSSION

The enamel alkyd olive-drab formulations, TT-E-527 and TT-E-529, and the enamel alkyd camouflage forest-green formulation, MIL-E-52798A, are moderately susceptible to fungal contamination, while the chemical agent resistant formulation, MIL-C-46168A, is slightly susceptible. Overgrinding or the incorporation of vesiculated beads into these formulations to improve texture smoothness does not provide an improvement in protection. The incorporation of 1% or 2% Vancide to prevent contamination did improve the resistance of the enamel alkyd

camouflage forest-green formulation by delaying the onset of growth and by reducing final growth levels, but these additions provided only minimal benefit in the chemical agent resistant formulation.

With Vancide incorporation into the enamel alkyd camouflage forest-green formulation and subsequent carbon arc exposure, there was a loss of protection with increasing exposure time. This was not the case with the fluorescent and xenon exposures. Fluorescent exposures resulted in a bleaching effect on paint color which did not result with carbon or xenon exposures.

In general, it appeared that the inherent susceptibility of the paint formulations (enamel alkyd > aliphatic polyurethane) provides the basis for fungal attack, and the degree of surface smoothness provides little change in this characteristic. This finding would tend to refute the thought that the texture of the painted surface is important in susceptibility due to the adherence of debris. However, outdoor exposure studies will be able to fully answer this point, as accelerated weathering studies can not fully simulate the role of deposited organic and inorganic debris in the fungal colonization process.

The use of Vancide in susceptible formulations (enamel alkyd) may afford some protection, but with extended periods of weathering this protection may be lost, as was the case with the carbon arc exposures. With an inherently less susceptible formulation, like the polyurethane, the incorporation of Vancide provides little advantage toward improving protection from fungal contamination. Vancide may not be the optimum biocide for this application. Other biocides should be evaluated for this purpose.

It is also apparent that a 28-day test for tropical chamber exposure is not long enough to fully illustrate the differences between the paint formulations. A three-month test period accomplishes this need.

A final report on the results of these studies will be completed once the remaining aspects of the work are finished. This will include the results of visible and infrared reflectance of the panels, before and after weathering and fungal exposure to assess changes in camouflage characteristics, testing for chemical agent penetration under these same conditions, completion of scanning electron microscopy to examine fungal penetration of the paint coatings, and the evaluation of the same paint formulations, but on a wooden matrix to assess the role of substrate in paint susceptibility.

CONCLUSIONS

Military paints, TT-E-527 and TT-E-529 (enamel alkyd olive drab), MIL-E-52798A (enamel alkyd camouflage forest green) and MIL-C-46168A (chemical agent resistant) were evaluated for fungal resistance characteristics. Accelerated weathering and leaching tests were run on painted metal panels followed by evaluation in plate tests and tropical chamber exposures. Paint formulations also included variables for texture (overgrind and vesiculated beads) and for biocide incorporation (1% and 2% Vancide 89RE). In general, results indicated the TT-E-527, TT-E-529 and MIL-E-52798A formulations supported moderate fungal growth after six weeks in plate tests or 13 weeks in tropical chamber tests. MIL-C-46168A supported slight growth during these time frames. Overgrinding or the inclusion of vesiculated beads did not improve fungal resistance of either

the MIL-E-52798A or MIL-C-46168A formulations. The incorporation of 1% or 2% Vancide significantly improved the fungal resistance of MIL-E-52798A, but provided only minimal improvement for MIL-C-46168A.

REFERENCES

American Society for Testing and Materials. 1982. Annual Book of ASTM Standards. Part 41. General Test Methods, Nonmetal; Laboratory Apparatus; Statistical Methods; Space Simulation; Durability of Non metallic Materials. Philadelphia, PA.

United States Department of the Army. 1978. Military Specification. Coating, Aliphatic Polyurethane, Chemical Agent Resistant. MIL-C-46168A (MR). US Army Materials and Mechanics Research Center, Watertown, Massachusetts.

United States Department of the Army. 1976. Military Specification. Enamel, Alkyd, Camouflage. MIL-E-52798A (ME). US Army Mobility Equipment Research and Development Command, Fort Belvoir, Virginia.

United States Department of the Air Force. 1975. Military Standard. Environmental Test Methods. MIL-STD-810C. Wright-Patterson Air Force Base, Ohio.

United States Department of the Army. 1969. Military Specification. Enamel, Alkyd, Lustreless. MIL-TT-E-527C. US Army Materials and Mechanics Research Center, Watertown, Massachusetts.

United States Department of the Army. 1969. Military Specification. Enamel, Alkyd, Semi-gloss. MIL-TT-E-529C. US Army Materials and Mechanics Research Center, Watertown, Massachusetts.

United States Government Printing Office. 1978. Federal Standards for Textile Test Methods. FED. TEST METHOD STD. No. 191A. Washington, DC.

Appendix A. Plate Test Results

Appendix A. Plate Test Results
Table A-1. Six weeks with enamel alkyd olive-drab formulations.

	WEATHERING (hours)											
	CONTROLS		XENON				FLUORESCENT				CARBON	
FORMULATION	0(A)[1]	0(B)[1]	100	300	500	700	100	300	500	700	100	700
TT-E-527 (A-1)[2]	4.0[3]	-[4]	3.67	3.67	3.0	3.33	4.0	3.33	3.33	3.33	-	-
TT-E-529 (A-2)	4.0	-	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.5	-	-

[1]Controls - (A) = *Xenon, fluorescent*, (B) = *carbon arc*

[2]Refer to Table 1 for coating code

[3]0 = no growth, 1 = trace growth, 2 = sparse growth, 3 = light growth, 4 = moderate growth, 5 = heavy growth

[4]Not evaluated

Appendix A. Plate Test Results

Table A-2. Six weeks with enamel alkyd camouflage forest-green formulations (MIL-E-52798A).

	WEATHERING (hours)											
	CONTROLS		XENON				FLUORESCENT				CARBON	
FORMULATION	0(A)[1]	0(B)[1]	100	300	500	700	100	300	500	700	100	700
Control (B-1)[2]	3.0[3]	4.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	1.0
Overground (B-2)	3.67	3.0	3.67	3.33	3.0	3.0	3.0	3.0	3.0	3.0	3.0	1.5
Beads (B-3)	3.67	4.0	3.33	3.0	2.33	3.0	2.67	3.0	3.0	3.0	2.0	1.5
1% Vancide (B-4)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.33	2.0	2.0	1.5	2.0
2% Vancide (B-5)	1.33	2.0	1.0	1.67	1.67	1.67	2.0	2.0	1.67	1.33	1.5	3.0

[1]Controls - (A) = Xenon, fluorescent, (B) = carbon arc

[2]Refer to Table 1 for coating code

[3]0 = no growth, 1 = trace growth, 2 = sparse growth, 3 = light growth, 4 = moderate growth, 5 = heavy growth

Appendix A. Plate Test Results
Table A-3. Six weeks, with chemical agent resistant coatings (MIL-C-46168A).

			WEATHERING (hours)									
	CONTROLS		XENON				FLUORESCENT				CARBON	
FORMULATION	0(A)[1]	0(B)[1]	100	300	500	700	100	300	500	700	100	700
Control (C-1)[2]	1.67[3]	2.0	1.67	2.0	1.67	1.33	2.0	2.0	2.0	2.0	2.0	2.0
Beads (C-2)	1.33	1.0	2.0	1.67	1.0	1.33	1.33	1.33	1.67	1.67	1.5	1.0
1% Vancide (C-3)	0.33	0	1.0	1.67	1.33	1.67	0.67	0.67	0.67	1.0	1.0	1.5
2% Vancide (C-4)	0	0	0	0	0	0	0	0	0	0	0	0

[1]Controls - (A) = Xenon, fluorescent, (B) = carbon arc

[2]Refer to Table 1 for coating code

[3]0 = no growth, 1 = trace growth, 2 = sparse growth, 3 = light growth, 4 = moderate growth, 5 = heavy growth

Appendix B. Chamber Test Results

Appendix B. Chamber Test Results

Table B-1. Enamel alkyd olive-drab formulations.

Formulation	Weathering (hours)	1	2	3	4	6	8	10	12	13
A. Xenon -		Chamber exposure (weeks)								
TT-E-527	0	0[2]	0	1.0	1.0	2.5	5.0			
(A-1)[1]	100	0	0	0.5	1.0	1.5	3.0	3.5	3.5	3.5
	300	0	0	1.0	1.0	1.5	3.0	3.5	3.5	3.5
	500	0	0	0.5	0.5	1.0	2.0	2.0	3.0	3.0
	700	0	0	0.5	0.5	1.0	2.5	3.5	3.5	3.5
TT-E-529	0	0	0	1.0	1.5	2.5	4.5	4.5	4.5	4.5
(A-2)	100	0	0	1.0	1.0	2.0	4.0	4.5	4.5	4.5
	300	0	0	1.0	1.5	2.5	4.0	4.5	4.5	4.5
	500	0	0	1.0	1.0	2.0	4.0	4.0	4.0	4.0
	700	0	0	1.0	1.5	2.0	3.5	4.0	4.5	4.5
B. Fluorescent										
TT-E-527	100	0	0	1.0	1.5	2.5	3.0	3.0	3.5	4.0
(A-1)	300	0	0	1.0	1.5	2.5	4.5	4.5	4.5	4.5
	500	0	0	1.0	1.5	2.0	3.5	3.5	4.0	4.0
	700	0	0	1.0	1.5	2.5	4.0	4.0	4.0	4.0
TT-E-529	100	0	0	1.0	2.0	3.0	4.5	5.0		
(A-2)	300	0	0	1.5	2.0	2.5	5.0			
	500	0	0	1.5	2.0	3.0	5.0			
	700	0	0	1.5	2.0	3.0	5.0			
C. Carbon-arc										
TT-E-527	0 (leached)	1.3	2.3	3.0	3.3	4.7	4.7	4.7	4.7	5.0
(A-1)	100	1.0	1.7	2.0	2.7	2.3	2.3	2.3	3.0	3.7
	300	1.0	1.0	1.3	2.0	2.0	2.0	2.0	2.3	2.7
	500	1.0	1.0	1.0	1.3	1.3	2.0	2.0	2.0	2.3
	700	0.7	1.0	1.0	1.3	1.3	2.0	2.0	2.3	2.7
TT-E-529	0 (leached)	1.0	2.0	2.7	3.0	4.7	5.0			
(A-2)	100	1.0	1.0	2.0	2.3	4.3	4.7	4.7	4.7	4.7
	300	1.0	1.0	1.0	1.7	4.0	4.3	4.3	4.3	4.7
	500	0.3	0.3	0.7	1.3	3.7	4.0	4.0	4.0	4.0
	700	0.3	0.7	0.7	1.3	3.0	3.0	3.0	3.0	3.3

[1]Refer to table 1 for coating code.

[2]0 = no growth, 1 = trace growth; 2 = 1-10%, sparse growth; 3 = 10-30%, light growth; 4 = 30-70%, moderate growth; 5 = 70-100%, heavy growth.

Appendix B. Chamber Test Results

Table B-2. Enamel alkyd camouflage forest-green formulations (MIL-E-52798A).

A. Xenon -

		Chamber exposure (weeks)								
Formulation	**Weathering (hours)**	**1**	**2**	**3**	**4**	**6**	**8**	**10**	**12**	**13**
Control (B-1)[1]	0	0[2]	0	1.0	1.5	3.5	4.0	4.5	4.5	4.5
	100	0	0	1.0	1.5	2.0	3.0	3.5	3.5	4.0
	300	0	0	1.0	1.5	2.5	3.0	3.5	3.5	3.5
	500	0	0	0.5	1.0	2.0	3.0	3.0	3.0	3.0
	700	0	0	0.5	0.5	1.5	2.5	3.0	3.0	3.0
Overground (B-2)	0	0	0	1.5	2.5	3.0	4.0	4.0	4.5	4.5
	100	0	0	1.0	1.5	2.5	3.5	3.5	3.5	3.5
	300	0	0	1.0	1.0	2.0	3.5	3.5	3.5	3.5
	500	0	0	0.5	1.0	1.5	2.0	3.5	3.5	3.5
	700	0	0	1.0	1.0	1.5	3.0	4.0	4.0	4.0
Beads (B-3)	0	0	0	0	0	1.5	3.0	3.0	2.5	3.0
	100	0	0	0	0.5	1.0	2.5	3.0	4.0	4.0
	300	0	0	0	0	1.0	3.0	3.5	4.0	4.5
	500	0	0	0	0	0	2.5	2.5	2.5	2.5
	700	0	0	0	0	0	3.0	3.5	4.0	4.5
1% Vancide (B-4)	0	0	0	0	0	0	1.0	1.5	1.5	1.5
	100	0	0	0	0	0	1.0	1.0	1.0	1.0
	300	0	0	0	0	0	1.0	1.5	1.5	2.0
	500	0	0	0	0	0.5	1.5	2.0	2.5	2.5
	700	0	0	0	0	0.5	1.5	2.0	2.0	2.5
2% Vancide (B-5)	0	0	0	0	0	0	1.0	1.5	1.5	1.5
	100	0	0	0	0	0	1.0	1.0	1.0	1.0
	300	0	0	0	0	0	1.0	1.0	1.0	1.0
	500	0	0	0	0	0	1.0	1.0	1.0	1.0
	700	0	0	0	0	0	1.0	1.0	1.0	1.0

Table B-2. Continued

B. Fluorescent -

Formulation	Weathering (hours)	1	2	3	4	6	8	10	12	13
		Chamber exposure (weeks)								
Control (B-1)	100	0	0	1.5	2.0	2.0	2.5	3.0	3.0	3.0
	300	0	0	1.5	1.5	2.0	2.5	3.0	3.0	3.0
	500	0	0	0.5	1.0	2.0	2.5	3.0	3.0	3.0
	700	0	0	0.5	1.5	2.0	2.5	3.0	3.0	3.0
Overground (B-2)	100	0	0.5	1.5	2.0	2.5	3.5	4.5	4.5	4.5
	300	0	0	1.0	2.0	2.5	3.0	3.5	3.5	3.5
	500	0	0	1.0	2.0	3.0	3.0	3.5	3.5	3.5
	700	0	0	1.0	2.0	2.5	3.5	3.5	3.5	3.5
Beads (B-3)	100	0	0	0	1.0	1.5	3.0	3.5	4.0	5.0
	300	0	0	1.0	1.0	2.0	3.0	3.0	4.0	5.0
	500	0	0	0.5	0.5	2.0	4.0	4.5	4.5	4.5
	700	0	0	1.0	1.0	2.0	3.0	3.0	3.5	4.0
1% Vancide (B-4)	100	0	0	0	0	0	0.5	1.0	1.5	1.5
	300	0	0	0	0	0	1.0	1.0	1.0	1.0
	500	0	0	0	0	0	1.0	1.5	1.5	1.5
	700	0	0	0	0	0	1.0	1.0	1.0	1.0
2% Vancide (B-5)	100	0	0	0	0	0	0.5	1.0	1.0	1.0
	300	0	0	0	0	0	0.5	1.0	1.0	1.0
	500	0	0	0	0	0	0.5	1.0	1.0	1.0
	700	0	0	0	0	0	0.5	1.0	1.0	1.0

Table B-2. Continued

C. Carbon Arc -

Formulation	Weathering (hours)	Chamber exposure (weeks) 1	2	3	4	6	8	10	12	13
Control (B-1)	0 (leached)	1.3	2.7	3.0	3.0	4.3	4.7	4.7	4.7	5.0
	100	1.0	2.0	2.0	2.3	4.0	4.0	4.0	4.0	4.7
	300	1.0	1.3	1.3	1.7	3.0	3.0	3.0	3.0	3.7
	500	1.0	1.0	1.0	1.0	3.0	3.0	3.3	3.3	3.3
	700	1.0	1.0	1.0	1.0	2.3	2.3	2.3	2.3	3.0
Overground (B-2)	0 (leached)	1.0	1.7	2.3	3.0	4.0	4.7	5.0		
	100	0.3	1.0	1.0	1.7	3.0	3.7	4.0	4.3	5.0
	300	1.0	1.0	1.0	1.3	1.7	2.0	3.0	3.7	4.3
	500	0.7	0.7	1.0	1.3	1.3	1.7	2.0	3.0	3.0
	700	0.3	0.3	0.7	0.7	1.3	1.7	2.3	3.3	4.0
Beads (B-3)	0 (leached)	0.7	1.3	1.7	2.7	3.7	3.7	4.0	4.0	4.7
	100	0.7	0.7	1.0	1.3	2.3	3.3	4.0	4.3	4.7
	300	0.3	1.0	1.0	1.0	1.3	2.0	3.0	3.7	4.0
	500	0.3	0.3	0.3	0.7	1.0	1.7	2.0	3.0	3.3
	700	0	0	0	0	1.0	1.7	2.0	2.3	3.3
1% Vancide (B-4)	0 (leached)	0	0	0	0	1.0	1.3	1.3	1.3	1.3
	100	0	0	0	0	1.0	2.0	2.0	2.3	2.3
	300	0.3	0.3	0.3	0.3	1.3	2.7	3.0	4.0	4.0
	500	0.7	0.7	0.7	1.0	1.3	3.3	4.0	5.0	
	700	0.7	1.0	1.0	1.0	2.0	3.3	3.3	4.7	4.7
2% Vancide (B-5)	0 (leached)	0	0	0	0	0.7	1.0	2.0	2.0	2.0
	100	0	0	0	0	0.7	1.0	1.0	1.3	1.3
	300	0	0	0	0	0.7	1.7	1.7	1.7	1.7
	500	0	0	0.7	0.7	1.3	2.3	2.3	2.7	3.7
	700	0	0	0.3	0.3	1.3	2.3	2.3	3.7	4.0

[1]Refer to table 1 for coating code.

[2]0 = no growth, 1 = trace growth; 2 = 1-10%, sparse growth; 3 = 10-30%, light growth; 4 = 30-70%, moderate growth; 5 = 70-100%, heavy growth.

Appendix B. Chamber Test Results
Table B-3. Chemical agent resistant coatings (MIL-C-46168A).

A. Xenon -

Formulation	Weathering (hours)	Chamber exposure (weeks) 1	2	3	4	6	8	10	12	13
Control	0	0[2]	0	0	0	0	0.8	2.0	2.0	2.0
(C-1)[1]	100	0	0	0	0	0	0.5	1.8	1.8	1.8
	300	0	0	0	0	0	0.8	2.0	2.0	2.0
	500	0	0	0	0	0	0.8	1.8	1.8	1.8
	700	0	0	0	0	0	0.5	2.0	2.0	2.0
Beads	0	0	0	0	0	0.2	1.2	2.0	2.0	2.0
(C-2)	100	0	0	0	0	0.5	1.0	2.0	2.0	2.0
	300	0	0	0	0	0	1.0	2.0	2.0	2.0
	500	0	0	0	0	0.5	1.2	1.8	2.0	2.0
	700	0	0	0	0	0	1.0	2.0	2.0	2.0
1% Vancide	0	0	0	0	0	0	0	1.8	1.8	1.8
(C-3)	100	0	0	0	0	0	0	1.8	1.8	2.0
	300	0	0	0	0	0	0	2.0	2.0	2.0
	500	0	0	0	0	0	0.2	2.0	2.2	2.2
	700	0	0	0	0	0	0.2	2.0	2.0	2.0
2% Vancide	0	0	0	0	0	0	0	1.8	1.8	1.8
(C-4)	100	0	0	0	0	0	0	1.8	2.0	2.0
	300	0	0	0	0	0	0	1.5	1.8	1.8
	500	0	0	0	0	0	0	1.5	1.8	1.8
	700	0	0	0	0	0	0	1.2	1.8	2.0

Table B-3. Continued

B. Fluorescent -

Formulation	Weathering (hours)	Chamber exposure (weeks) 1	2	3	4	6	8	10	12	13
Control (C-1)	100	0	0	0	0	0	1.0	2.0	2.0	2.2
	300	0	0	0	0	0	1.0	1.8	1.8	1.8
	500	0	0	0	0	0	1.0	1.2	1.2	1.5
	700	0	0	0	0	0	1.0	1.8	1.8	1.8
Beads (C-2)	100	0	0	0	0	0.2	1.0	2.2	2.5	2.5
	300	0	0	0	0.8	0.8	1.0	2.0	2.0	2.0
	500	0	0	0	0	0	1.0	2.0	2.0	2.0
	700	0	0	0	0	0	1.0	2.0	2.0	2.0
1% Vancide (C-3)	100	0	0	0	0	0	0.5	2.0	2.0	2.0
	300	0	0	0	0	0	0.5	1.5	1.5	1.5
	500	0	0	0	0	0	0.5	1.0	1.0	1.0
	700	0	0	0	0	0	0.5	1.0	1.0	1.0
2% Vancide (C-4)	100	0	0	0	0	0	0.2	1.0	1.0	1.8
	300	0	0	0	0	0	0.5	1.2	1.2	1.5
	500	0	0	0	0	0	0.5	1.0	1.0	1.0
	700	0	0	0	0	0	0.8	1.0	1.0	1.0

Table B-3. Continued

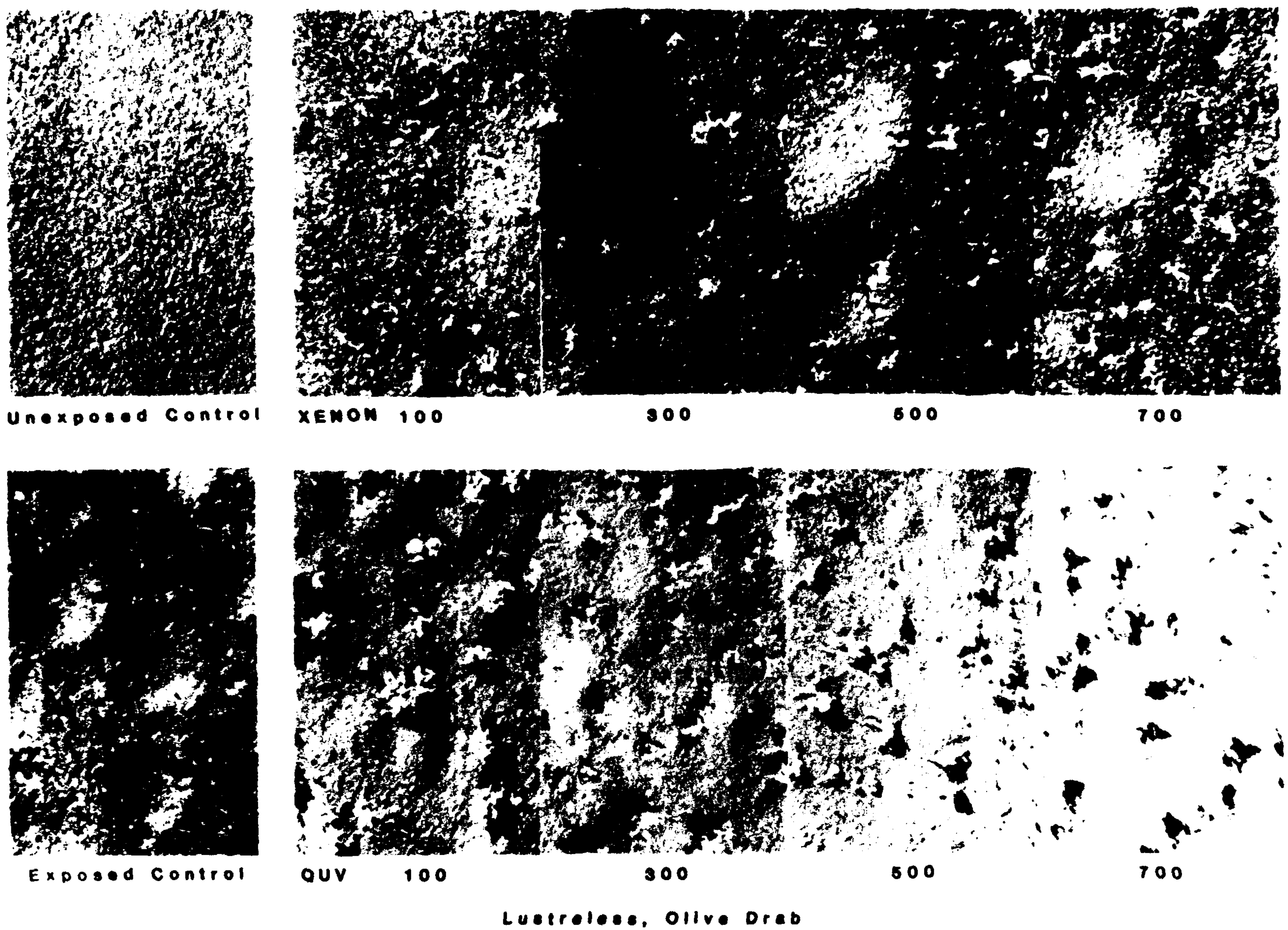
C. Carbon Arc -

Formulation	Weathering (hours)	Chamber exposure (weeks) 1	2	3	4	6	8	10	12	13
Control (C-1)	0 (leached)	0	0	0	0	1.5	2.0	2.0	2.0	2.2
	100	0	0	0	0	1.5	2.2	2.2	2.2	2.2
	300	0	0	0	0	1.2	2.0	2.0	2.0	2.0
	500	0	0	0	0	1.2	2.2	2.2	2.2	2.2
	700	0	0	0	0	1.5	2.2	2.2	2.2	2.2
Beads (C-2)	0 (leached)	0	0	0	0	1.0	2.2	2.2	2.2	2.8
	100	0	0	0	0	1.0	2.0	2.2	2.2	2.2
	300	0	0	0	0	1.0	2.0	2.2	2.2	2.5
	500	0	0	0	0	0.8	2.0	2.0	2.0	2.0
	700	0	0	0	0	1.0	1.8	1.8	1.8	2.0
1% Vancide (C-3)	0 (leached)	0	0	0	0	1.2	1.8	1.8	1.8	1.8
	100	0	0	0	0	1.0	2.0	2.0	2.0	2.2
	300	0	0	0	0	1.0	1.8	2.0	2.0	2.0
	500	0	0	0	0	1.2	2.0	2.0	2.0	2.2
	700	0	0	0	0	1.5	1.8	2.0	2.0	2.5
2% Vancide (C-4)	0 (leached)	0	0	0	0	0	1.0	1.0	1.0	1.0
	100	0	0	0	0	0.5	1.5	1.5	1.8	2.0
	300	0	0	0	0	0.5	1.2	1.5	1.5	1.5
	500	0	0	0	0	0.5	1.0	1.0	1.2	1.5
	700	0	0	0	0	0.5	1.0	1.2	1.5	1.8

[1]Refer to Table 1 for coating code.

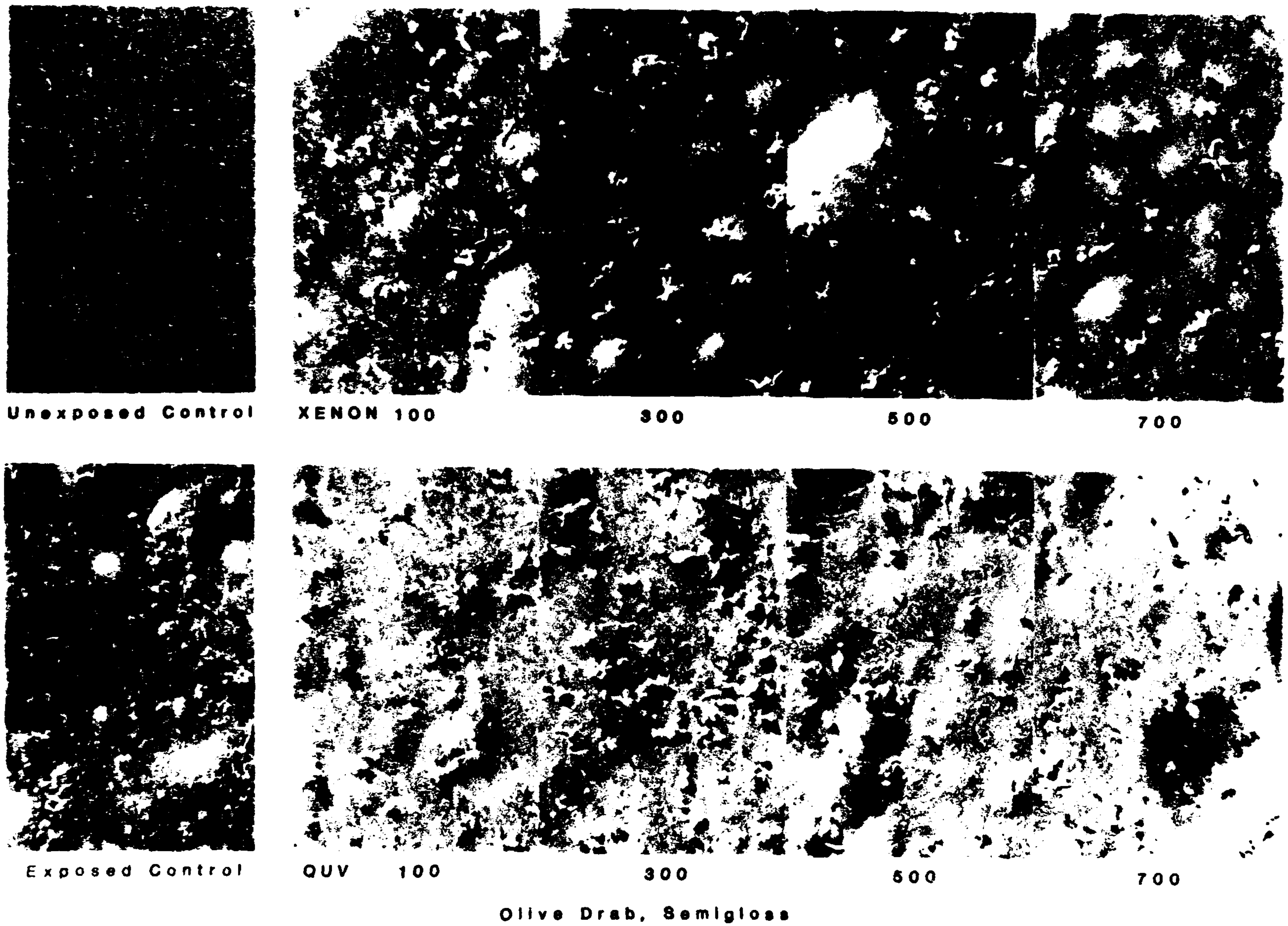
[2]0 = no growth, 1 = trace growth, 2 = 1-10%, sparse growth; 3 = 10-30%, light growth; 4 = 30-70%, moderate growth; 5 = 70-100%, heavy growth.

Appendix C. Photomicrographs

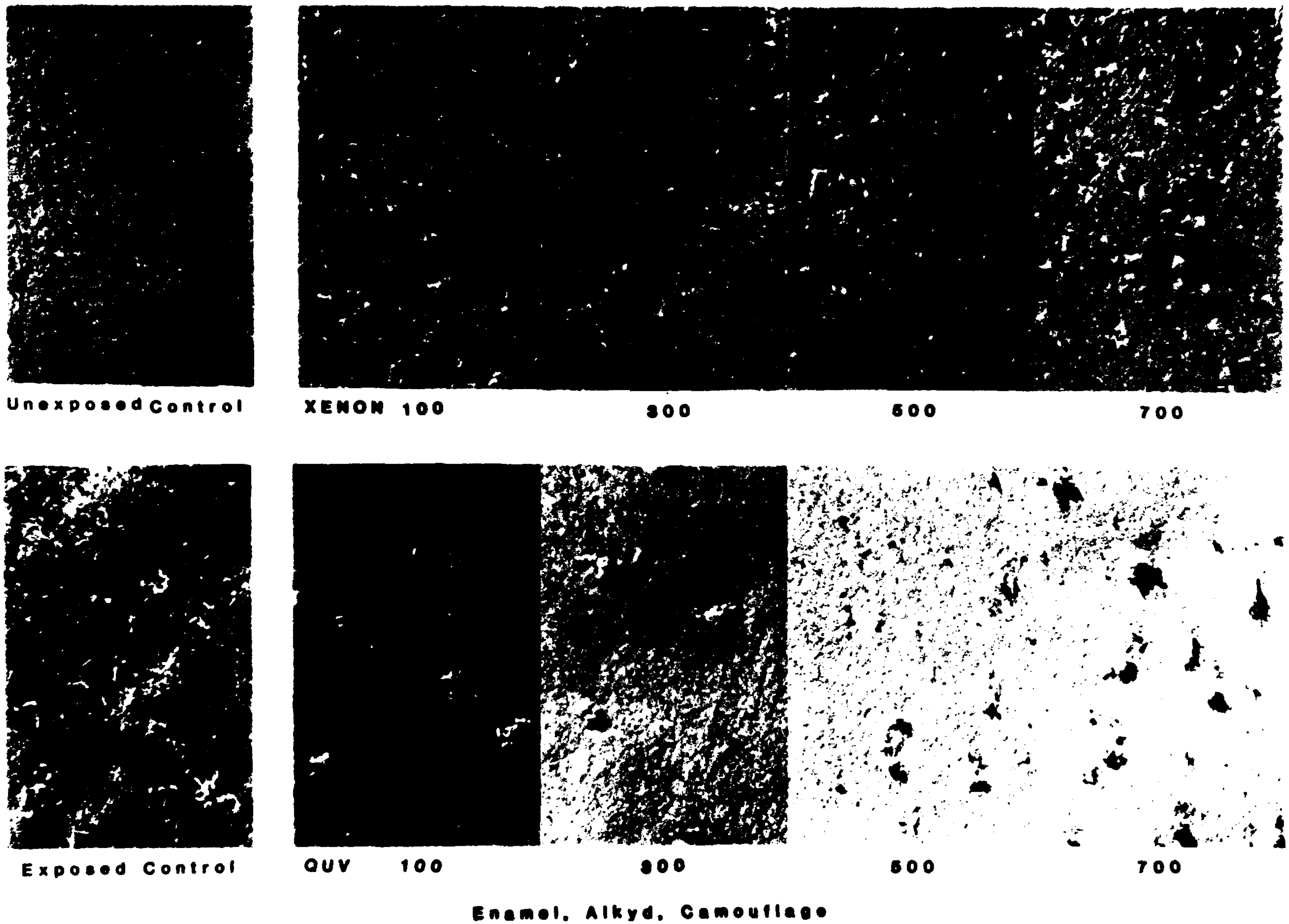


Appendix C. Photomicrographs

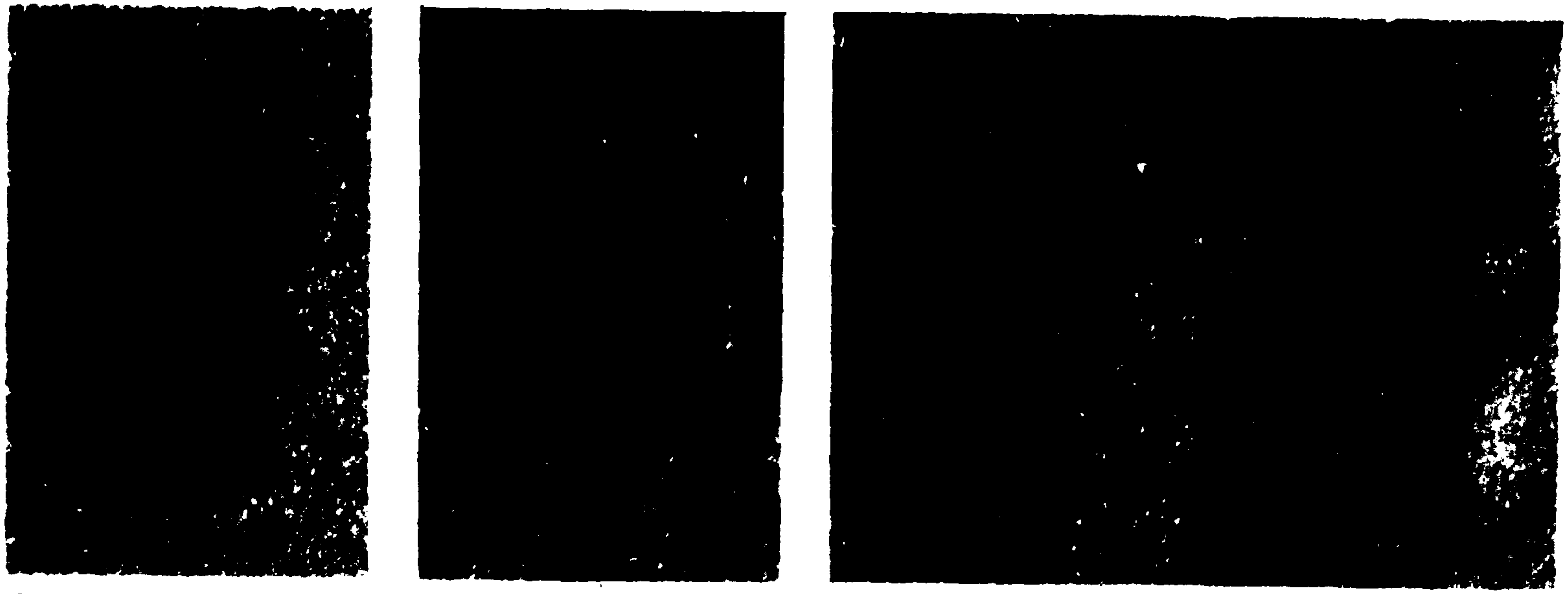
Figure C-1. Olive-Drab, TT-E-527, lustreless (A-1), before and after xenon and fluorescent exposures.



Appendix C. Photomicrographs
Figure C-2. Olive-Drab TT-E-529, semigloss (A-2), before and after xenon and fluorescent exposures.



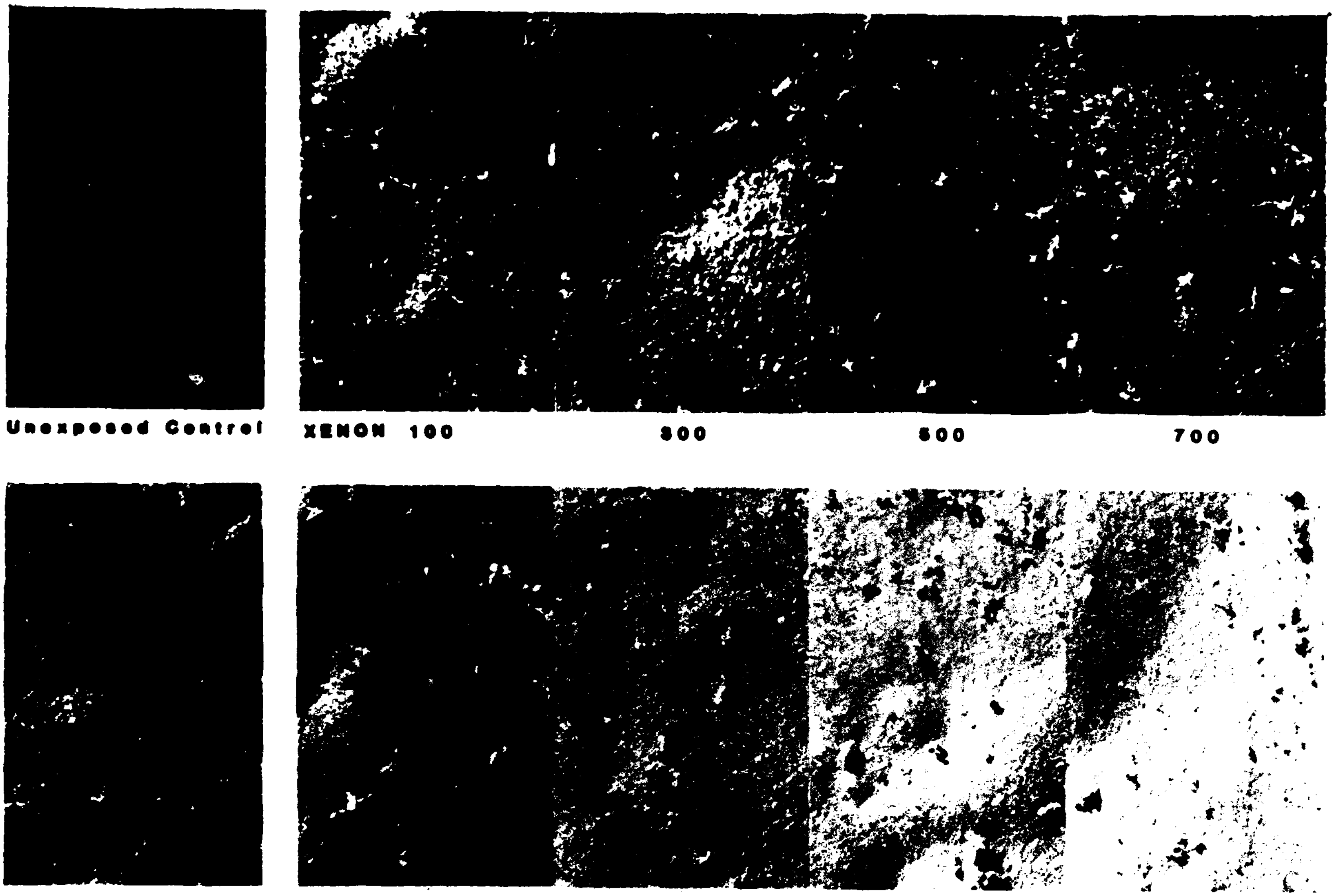
Appendix C. Photomicrographs
Figure C-3. Forest-Green, MIL-E-52798A, control (B-1), before and after xenon and fluorescent exposures.



Unexposed Control **Exposed Control** **Carbon 100** **700**

Enamel, Alkyd, Camouflage, Overground

Appendix C. Photomicrographs
Figure C-4. Forest-green, MIL-E-52798A, overground, (B-2), before and after carbon arc exposure

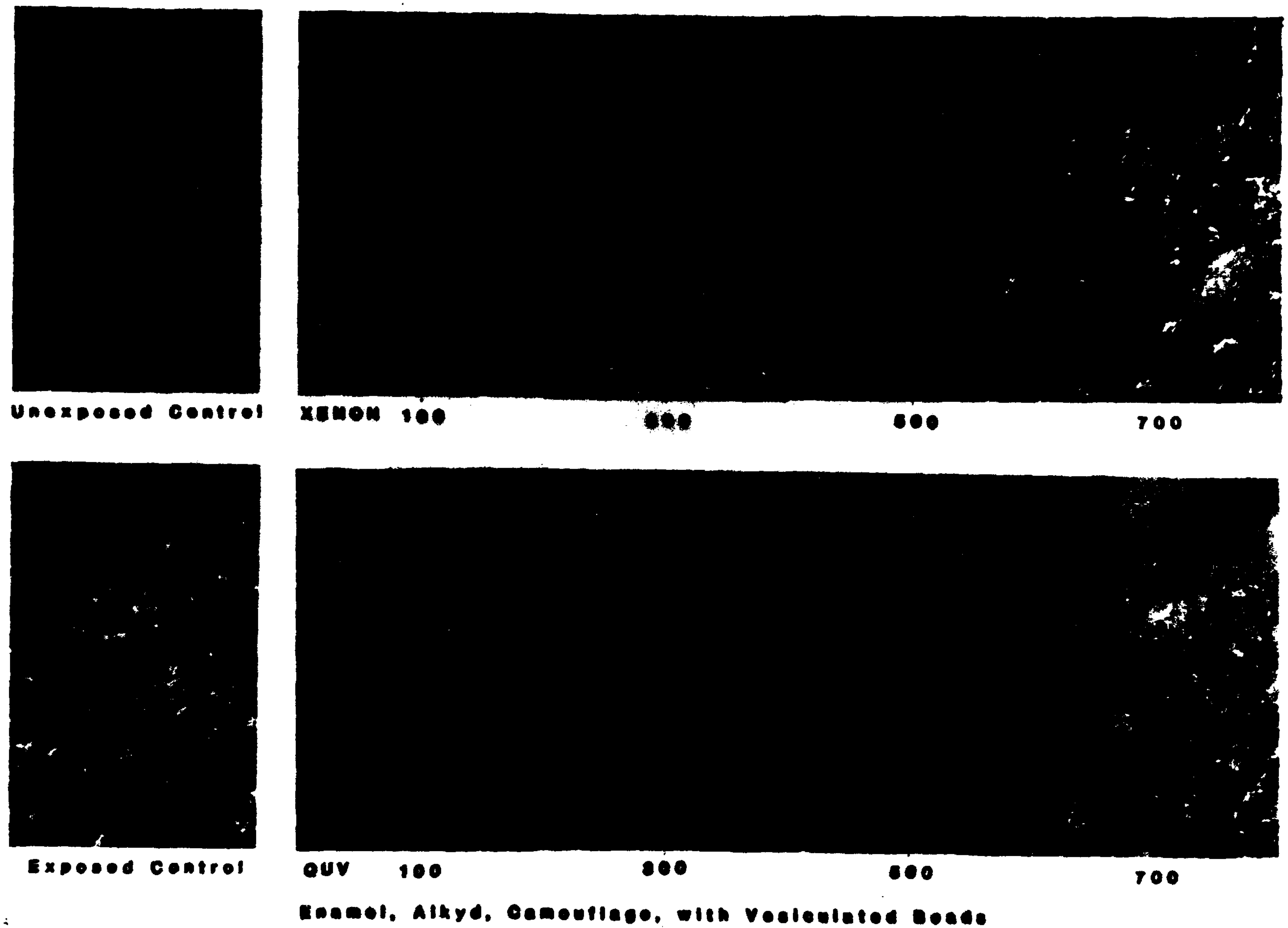


Unexposed Control XENON 100 300 500 700

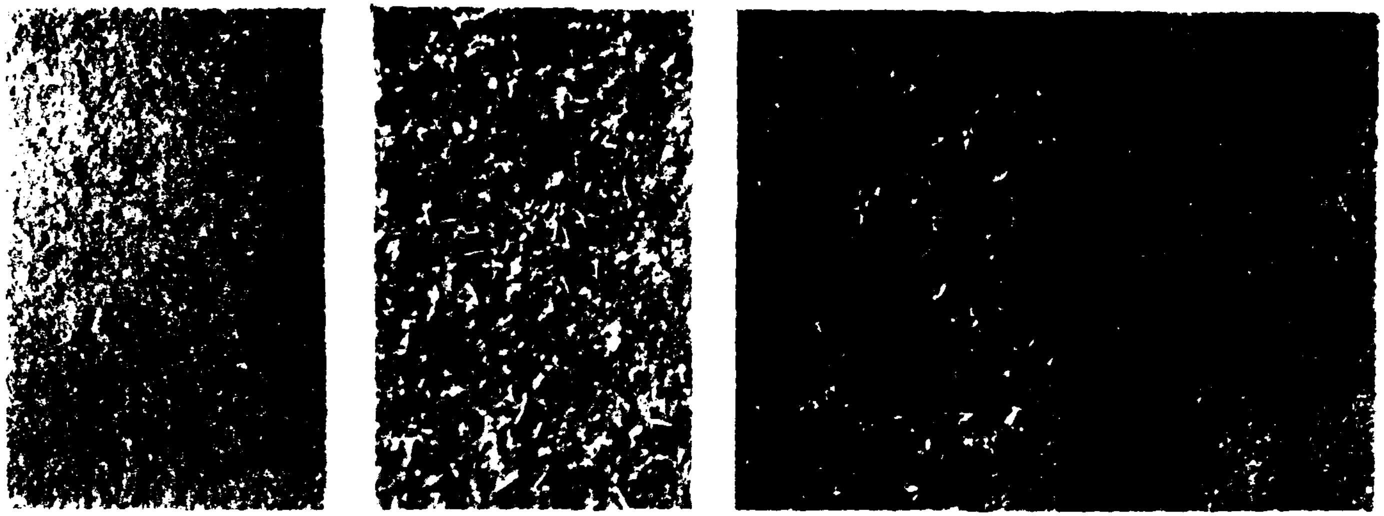
Exposed Control QUV 100 300 500 700

Enamel, Alkyd, Camouflage, Overground

Appendix C. Photomicrographs
Figure C-5. Forest-Green, MIL-E-52798A, overground, (B-2), before and after xenon and fluorescent exposures

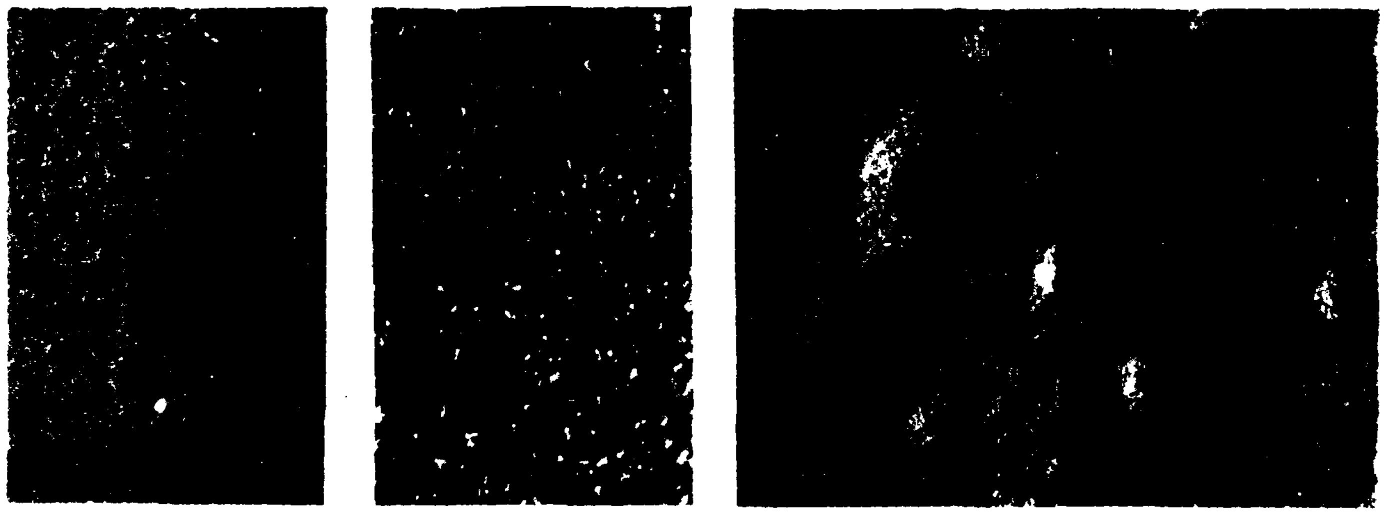


Appendix C. Photomicrographs
Figure C-6. Forest-Green, MIL-E-52798A, with beads, (B-3), before and after xenon and fluorescent exposures.



Unexposed Control | Exposed Control | Carbon 100 | 700

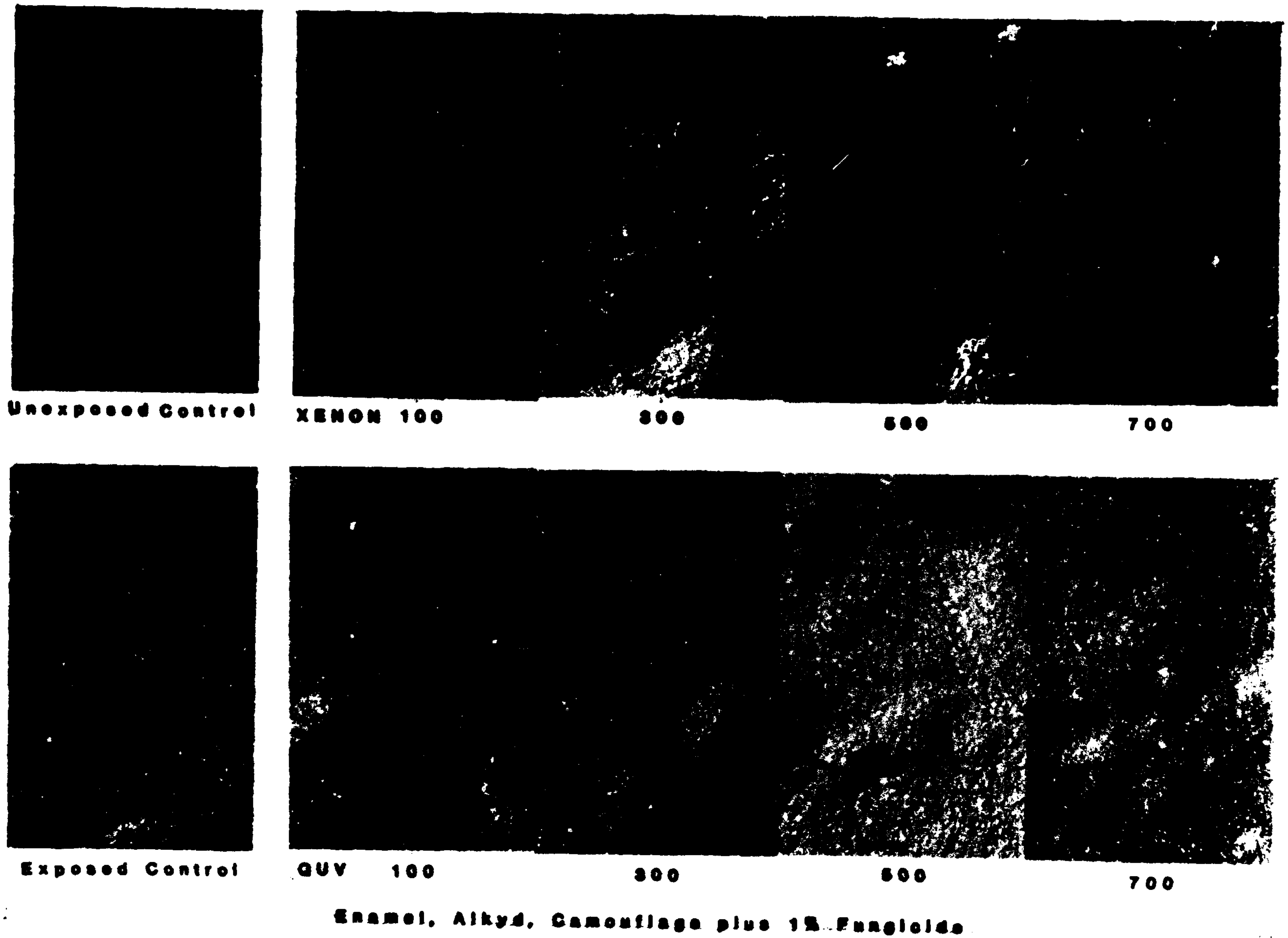
Enamel, Alkyd, Camouflage



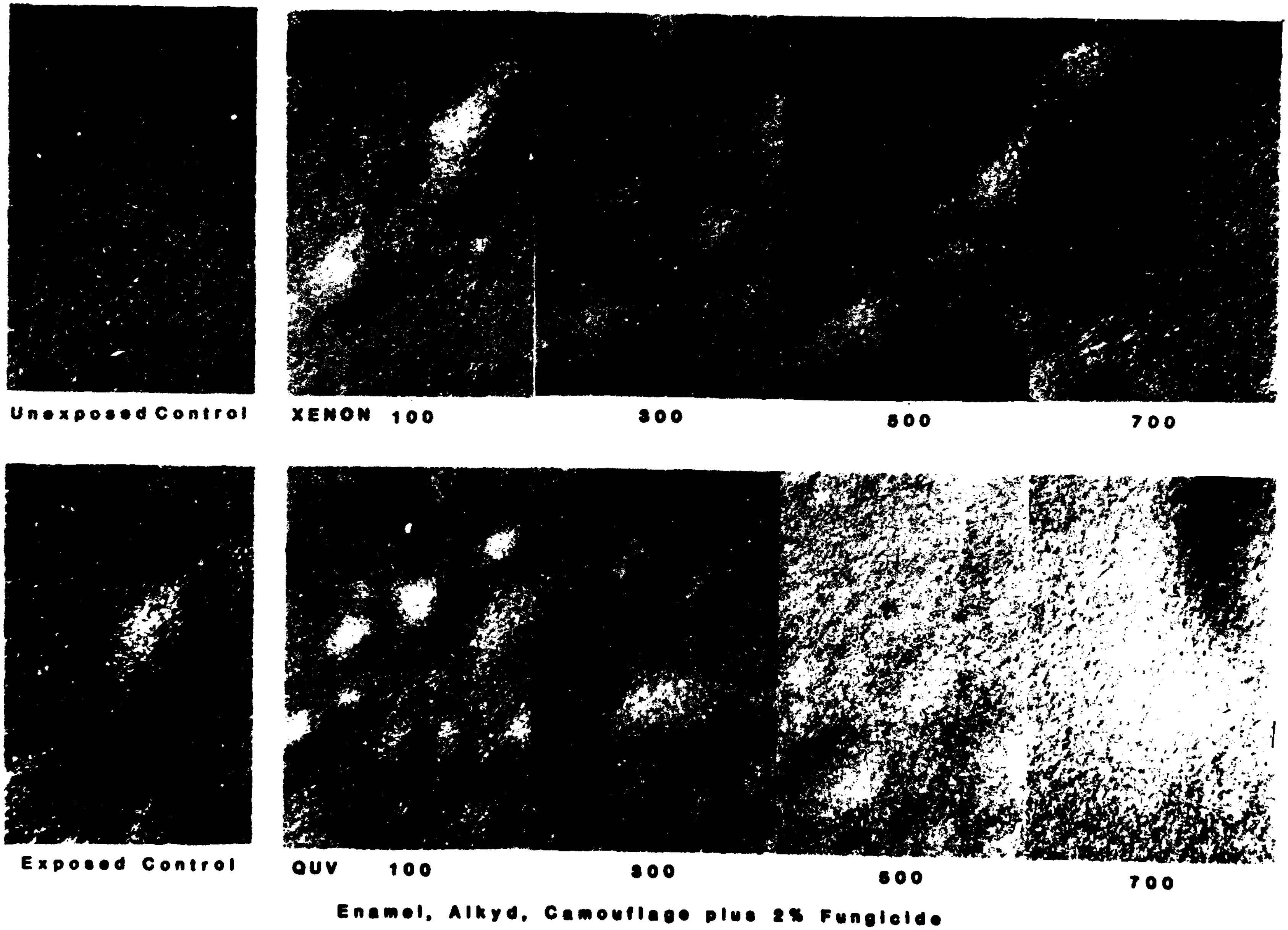
Unexposed Control | Exposed Control | Carbon 100 | 700

Enamel, Alkyd, Camouflage, with Vesiculated Beads

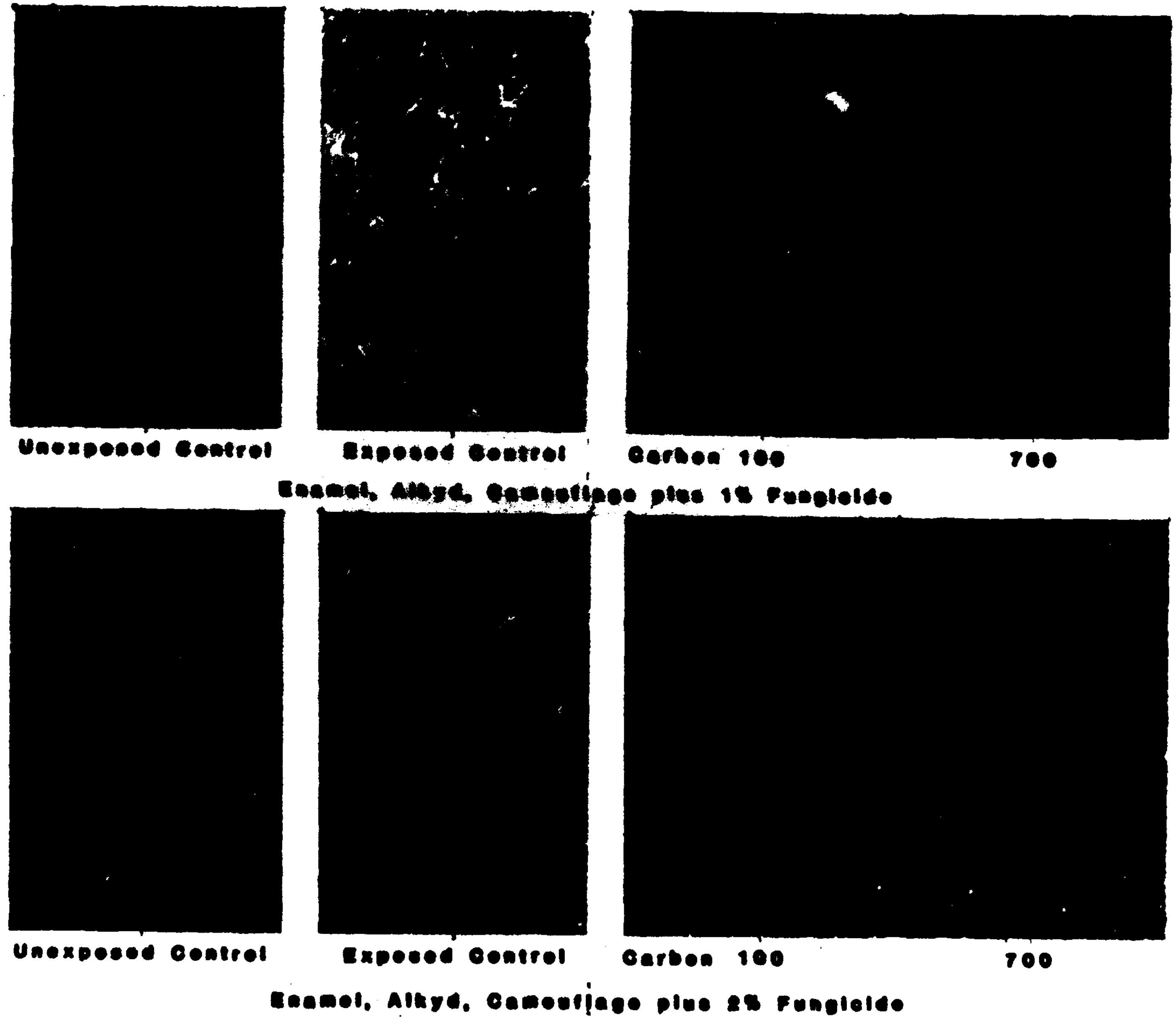
Appendix C. Photomicrographs
Figure C-7. Forest-Green, MIL-E-52798A, control (top), (B-1), and with beads (bottom), (B-3), before and after carbon arc exposure.



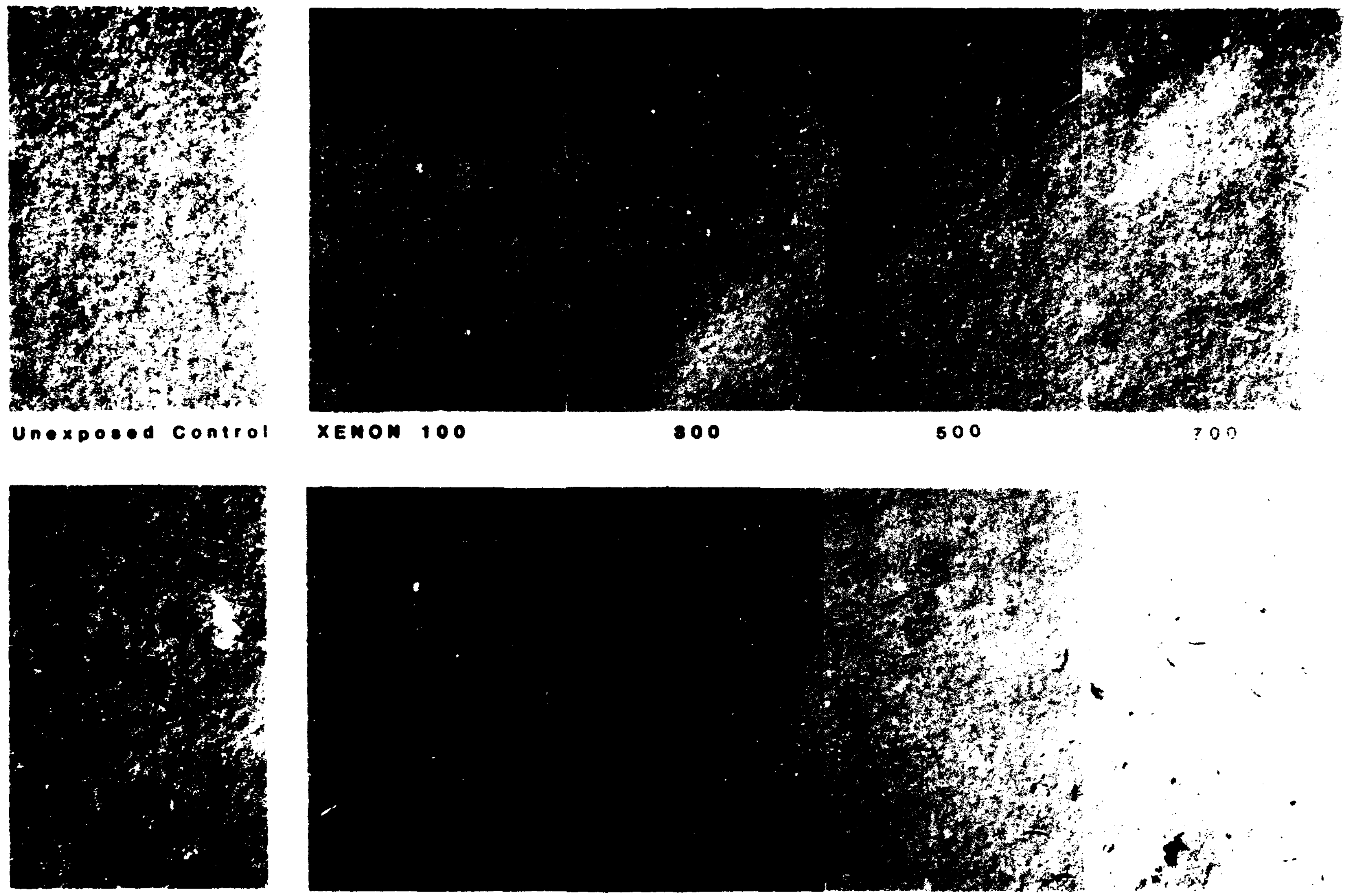
Appendix C. Photomicrographs
Figure C-8. Forest-Green, MIL-E-52798A, with 1% Vancide, (B-4), before and after xenon and fluorescent exposures.



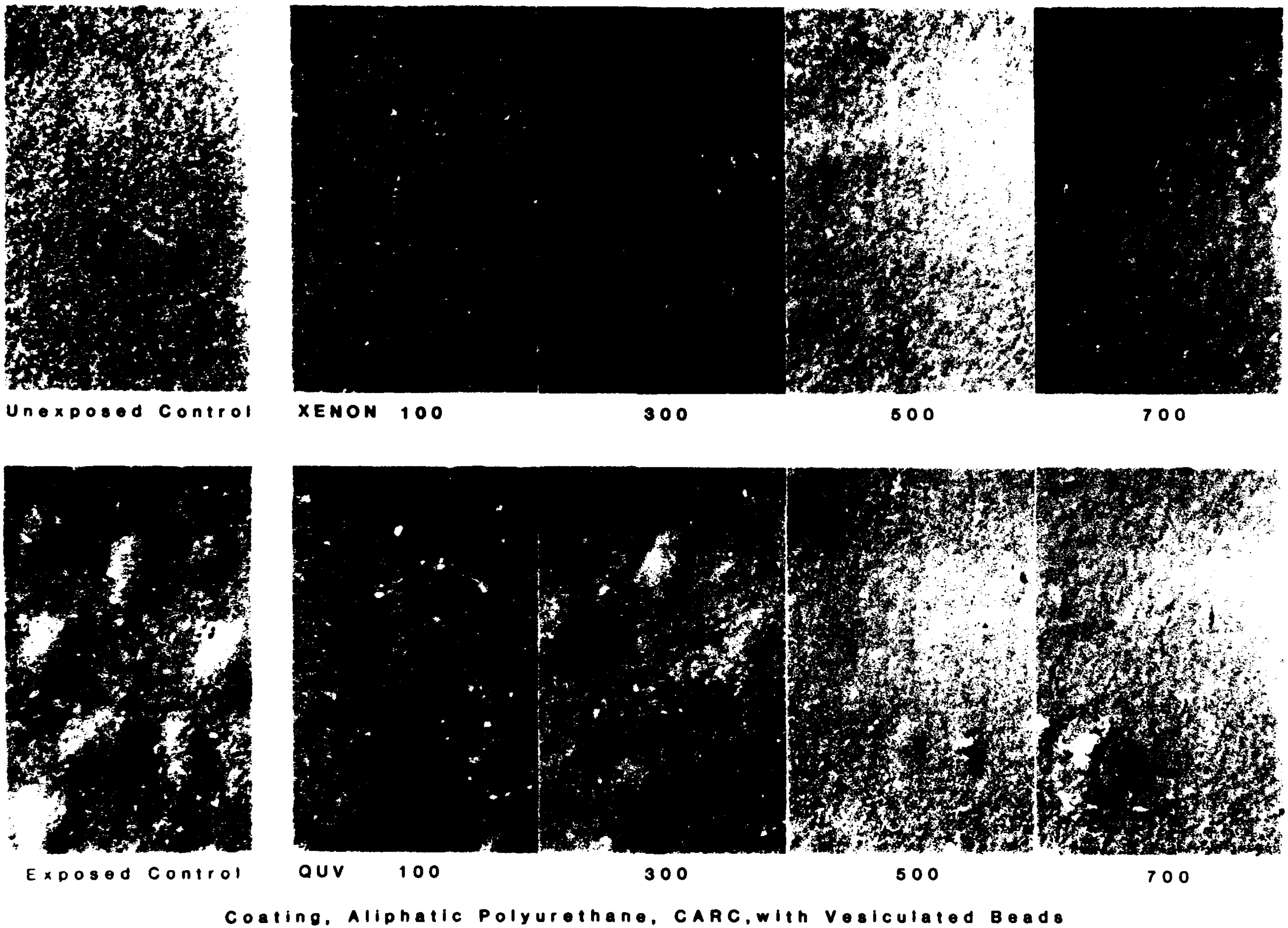
Appendix C. Photomicrographs
Figure C-9. Forest-Green, MIL-E-52798A, with 2% Vancide, (B-5), before and after xenon and fluorescent exposures.



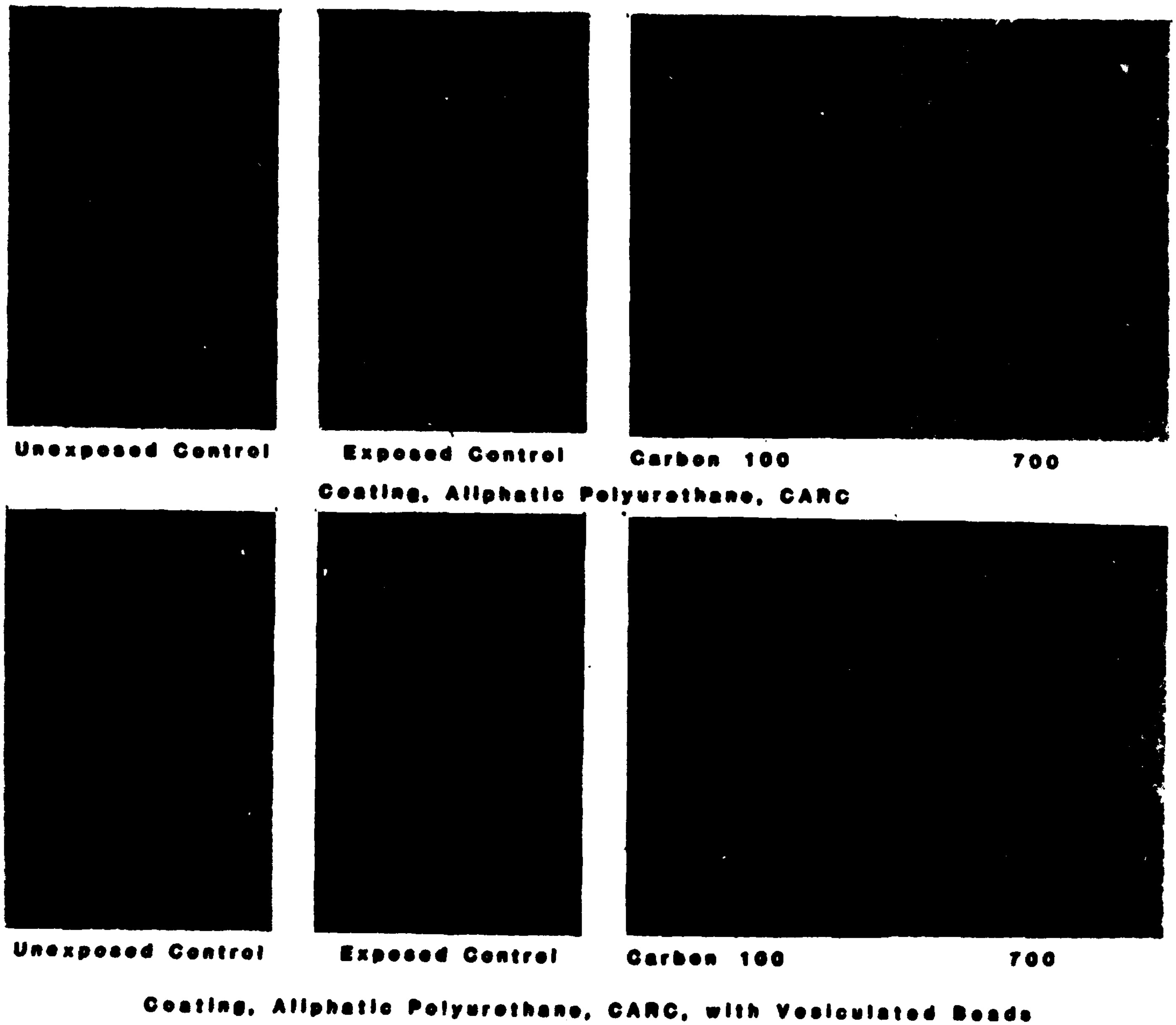
Appendix C. Photomicrographs
Figure C-10. Forest-Green, MIL-E-52798A, with 1% Vancide (top), (B-4), and 2% Vancide (bottom), (B-5), before and after carbon arc exposure.



Appendix C. Photomicrographs
Figure C-11. Chemical Agent Resistant Coating MIL-C-46168A, control, (C-1), before and after xenon and fluorescent exposure.

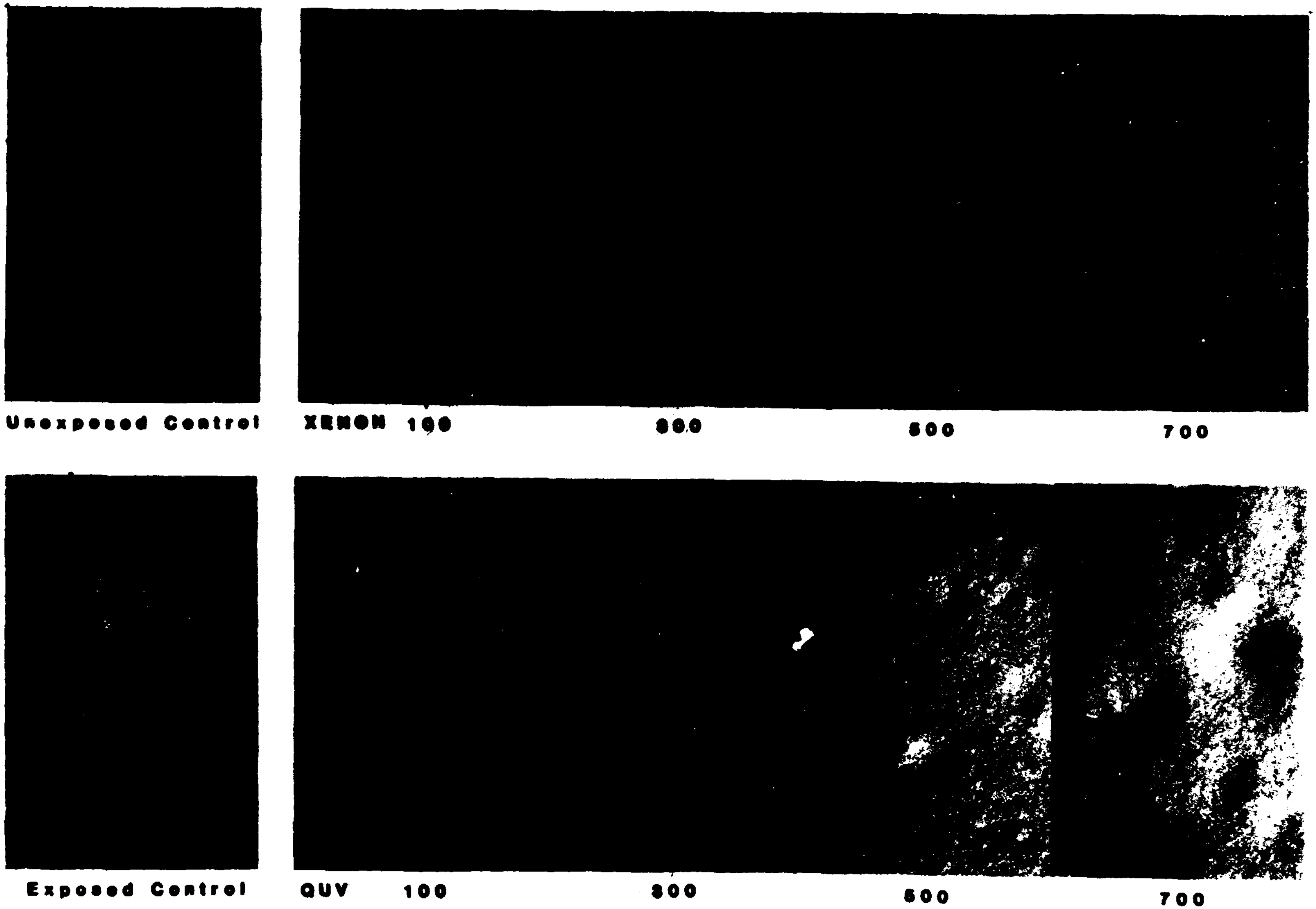


Appendix C. Photomicrographs
Figure C-12. Chemical Agent Resistant Coating MIL-C-46168A, with beads, (C-2), before and after xenon and fluorescent exposure.



Appendix C. Photomicrographs

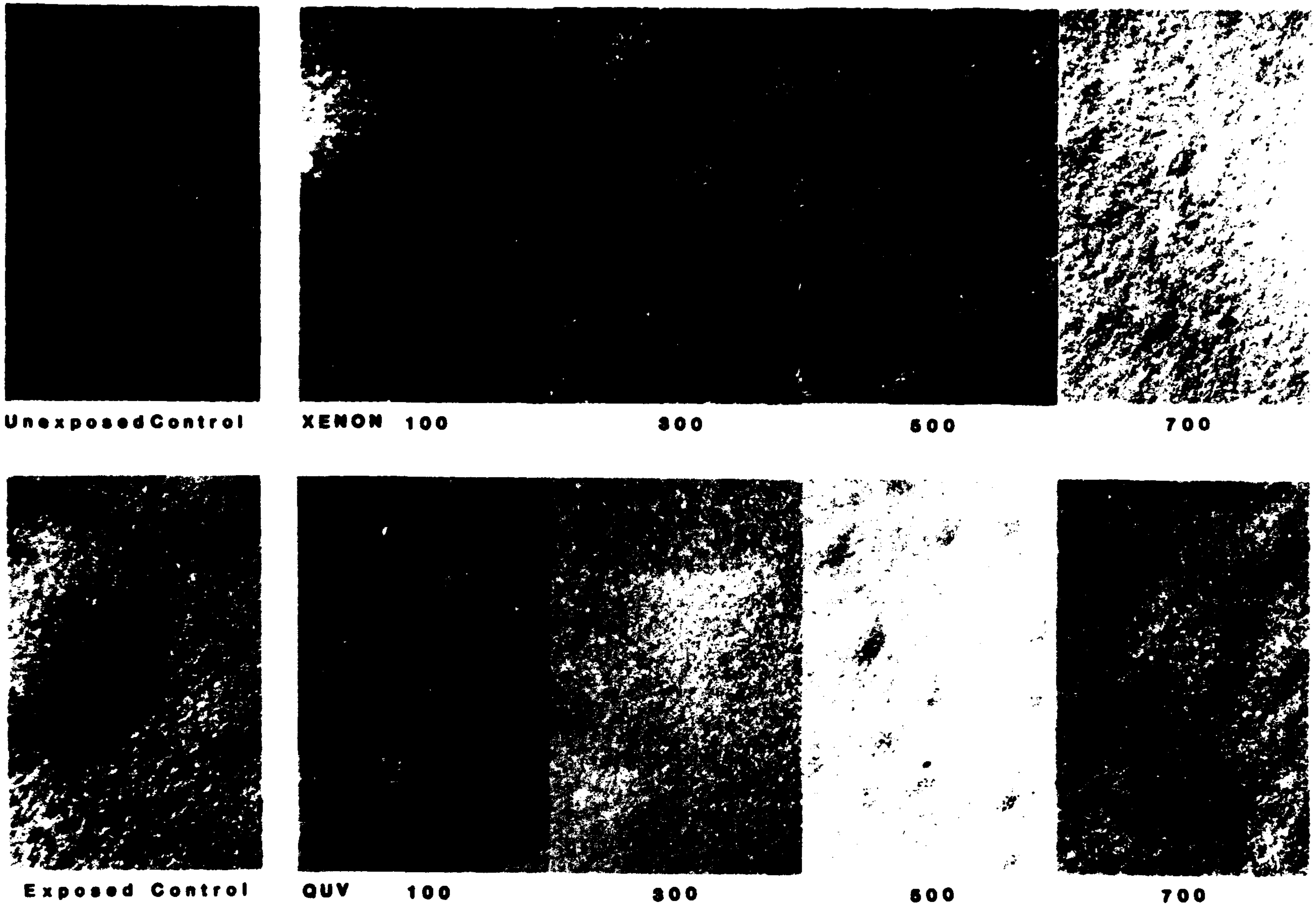
Figure C-13. Chemical Agent Resistant Coating, MIL-C-46168A, control (top), (C-1), and with beads (bottom), (C-2), before and after carbon arc exposure.



Coating, Aliphatic Polyurethane, CARC plus 1% Fungicide

Appendix C. Photomicrographs

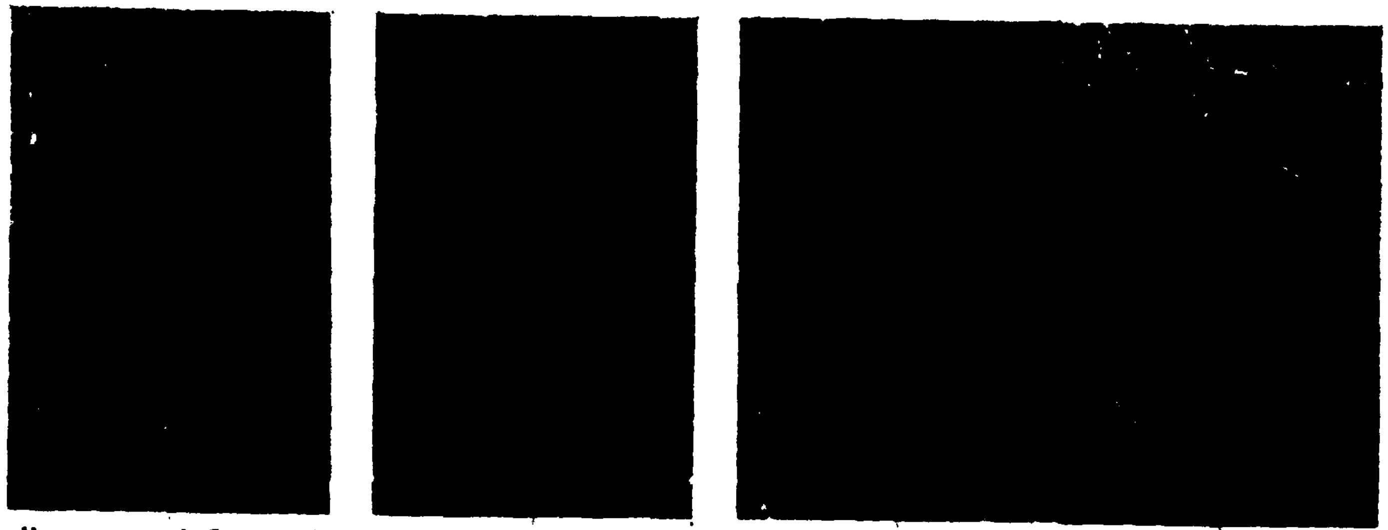
Figure C-14. Chemical Agent Resistant Coating, MIL-C-46168A, with 1% Vancide (C-3), before and after xenon and fluorescent exposures.



Coating, Aliphatic Polyurethane, CARC plus 2% Fungicide

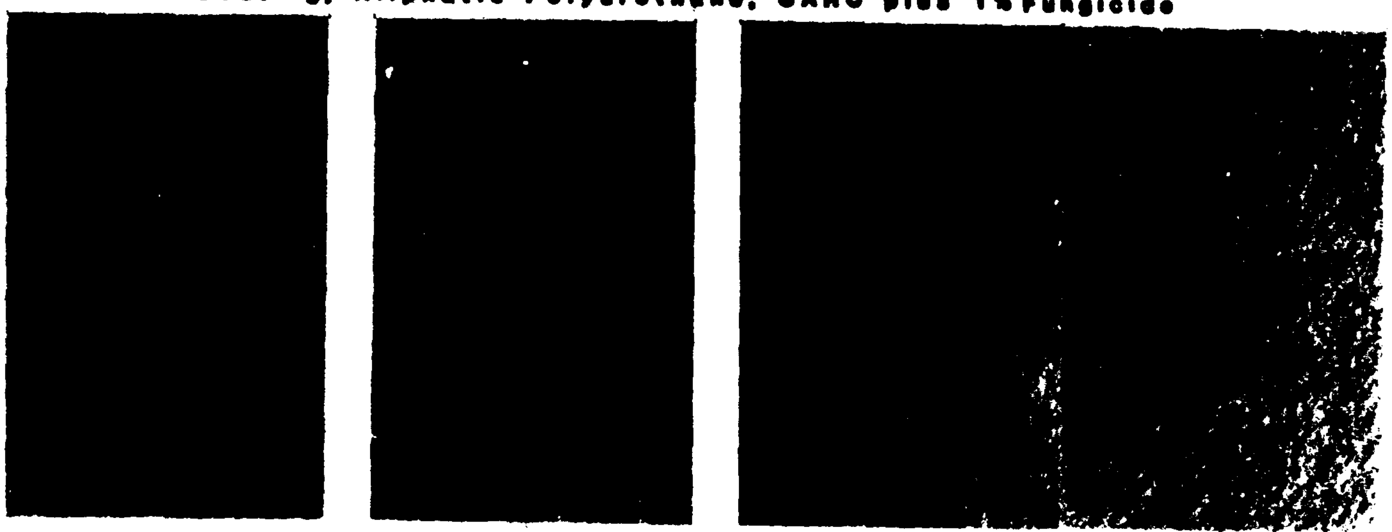
Appendix C. Photomicrographs

Figure C-15. Chemical Agent Resistant Coating, MIL-C-46168A, with 2% Vancide (C-4), before and after xenon and fluorescent exposures.



Unexposed Control Exposed Control Carbon 100 700

Coating, Aliphatic Polyurethane, CARC plus 1% Fungicide



Unexposed Control Exposed Control Carbon 100 700

Coating, Aliphatic Polyurethane, CARC plus 2% Fungicide

Appendix C. Photomicrographs
Figure C-16. Chemical Agent Resistant Coating MIL-C-46168A, with 1% Vancide (top), (C-3), and with 2% Vancide (bottom), (C-4), before and after carbon arc exposure.